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DEVELOPMENT OF INTERACTION CURVE OF THIN PLATE STRUCTURE

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ABSTRACT

The aim of the present study is the development of interaction curve for thin plate structures. Thin plates are lightweight, high-strength structural elements, prevalently used in ships, aircrafts, submarines, offshore drilling rigs, pressure vessels, bridges, and roofing units. Most of these structures are required to operate under harsh environmental loading conditions. And this plate is subjected to in-plane and transverse loading under different boundary conditions. These loading have been used to predict the stability and failure of the plates and hence the model is used to determine the structural behaviour of thin plate. And the element is analyzed using software ANSYS. Plate deflection is analyzed using the software and these result is compared with manual result, The variations in manual and software result are also plotted. In addition to that, the stresses and yield stress of plate under different boundary conditions will have to find out.. These results are used for the development of interaction curve of thin plate structure.

Keywords: Ansys, In-Plane Loading, Out of Plane Loading, Steel Rectangular Plate, Ship Structure, Simply Supported, Yield Stress.

1. INTRODUCTION

A plate is a structural element which is characterized by two key properties. Firstly, its geometric configuration is a three-dimensional solid whose thickness is very small when compared with other dimensions. Secondly, the effects of the loads that are expected to be applied on it only generate stresses whose resultants are, in practical terms, exclusively normal to the element's thickness. Most of ship structures and topside decks of offshore structures are composed of plates, which are normally fabricated by welding. Structural plate systems stiffened by ribs in one or two directions are widely used in buildings, bridges, ships, aircraft, and machines. The stiffeners grid may act as a skeleton of the structure, which bears the different types of loads it is subjected to, while the base plate layer of the plate acts as the skin whose main function is to transmit the distributed loads to the skeleton of the structure. These structures usually consist of a base or ground structure of uniform thickness forming what is called the skin of the structure in addition to local reinforcement elements called stiffeners or ribs to improve the static, dynamic and buckling characteristics. The efficiency of such sections is due to their use of the high in-plane stiffness of one plate element to support the edge of its neighbour, thus controlling the out-of-plane behavior of the latter.

The aim of the present study is to investigate the development of interaction curve for thin plate structures, when the plate is subjected to in-plane loading. These loading have been used to predict the stability and failure of the plates and hence the model was used to determine the structure strength. The plates are modeled using the finite element software. The advantage of the proposed element is that it can model plates with and without stiffeners within the element. Structure can be analyzed using software Ansys10. Development of interaction curve is from the output obtained from the Ansys10.

Thin plates are initially flat structural members bounded by two parallel planes, called faces, and a cylindrical surface, called an edge or boundary. The generators of the cylindrical surface are perpendicular to the plane faces. The distance between the plane faces is called the thickness (h) of the plate. It will be assumed that the plate thickness is small compared with other characteristic dimensions of the faces (length, width, diameter, etc.). Geometrically, plates are bounded either by straight or curved boundaries (Fig.1.1). The static or dynamic loads carried by plates are predominantly perpendicular to the plate faces.

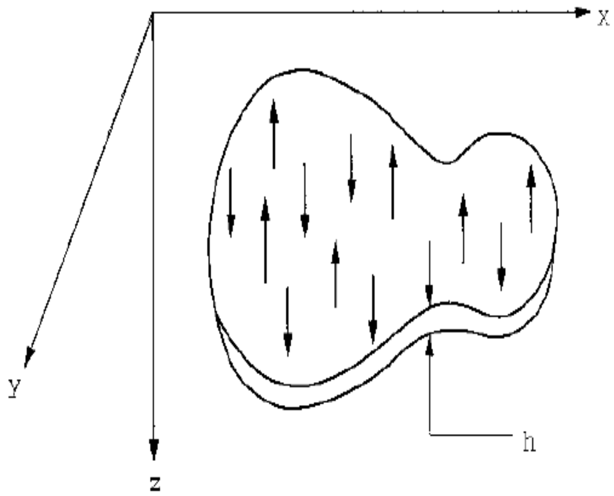


Fig 1.1: Plates are bounded by either straight or curved boundaries

The load-carrying action of a plate is similar, to a certain extent, to that of beams or cables; thus, plates can be approximated by a grid work of an infinite number of beams or by a network of an infinite number of cables, depending on the flexural rigidity of the structures. This two dimensional structural action of plates results in lighter structures, and therefore offers numerous economic advantages. The plate, being originally flat, develops shear forces, bending and twisting moments to resist transverse loads. Because the loads are generally carried in both directions and because the twisting rigidity in isotropic plates is quite significant, a plate is considerably stiffer than a beam of comparable span and thickness. So, thin plates combine light weight and a form efficiency with high load-carrying capacity, economy, and technological effectiveness.

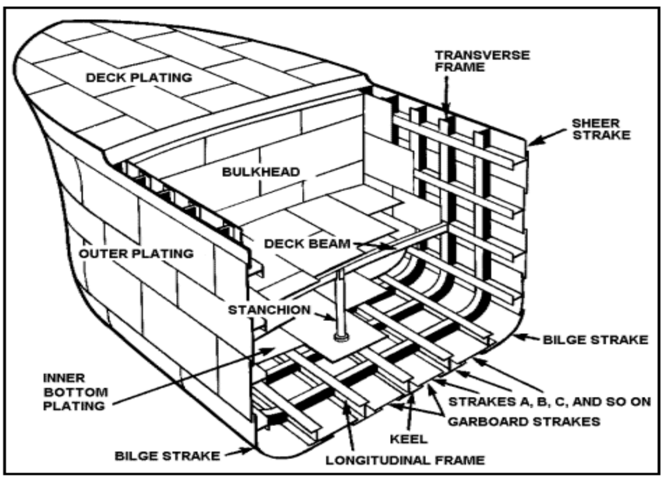


Fig: 1.1.2 Ship hull

Because of the distinct advantages discussed above, thin plates are extensively used in all fields of engineering. Plates are used in architectural structures, bridges, hydraulic structures, pavements, containers, airplanes, missiles, ships, instruments, machine parts, etc. (Fig. 1.1.3).

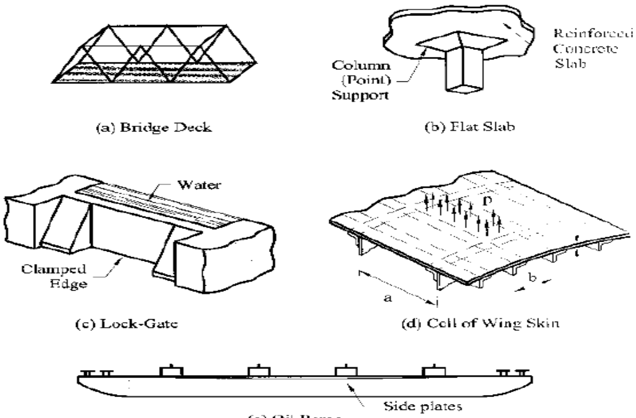


Fig 1.1.3: Applications of thin plate structure

1.1. Advantages

The load-carrying action of a plate is similar to a certain extent to that of beams or cables. Thus plates can be approximated by a grid work of an infinite number of beams or by a network of an infinite number of cables depending on the flexural rigidity of the structures. This two-dimensional structural action of plates results in lighter structures, and therefore offers numerous economic advantages. The plate being originally flat, develops shear forces, bending and twisting moments to resist transverse loads. Because the loads are generally carried in both directions and because the twisting rigidity in isotropic plates is quite significant, a plate is considerably stiffer than a beam of comparable span and thickness. So, thin plates combine light weight and form efficiency with high load-carrying capacity, economy, and technological effectiveness.

1.3 Applications

Because of the distinct advantages discussed above, thin plates are extensively used in all fields of engineering. Plates are used in architectural structures, bridges, hydraulic structures, pavements, containers, airplanes, missiles, ships, instruments, machine parts, etc.

1.4. Plate definitions

The plates may be unstiffened or stiffened. The plate is provided with continuous supports preventing out-of-plane displacements along all edges. The edges can be simply supported. It is also possible to apply rotational restraints along an edge or part of an edge .The number and orientation of stiffeners may be arbitrary. In addition, translational and rotational springs can be added along arbitrary oriented lines, in order to model restraints by a surrounding structure at the edges.

The external loading applied to the edges may consist of a combination of in-plane shear stress and linear varying in-plane compression or tension stress. The edges are free to move in the in-plane directions, but they are forced to remain straight, to reflect interaction with surrounding plates. Consequently, the total stress along the plate edges are those shown in Fig.1.4 plus those required to maintain straight edges. The latter stresses are obtained from the analysis, and their resultant over the length of an edge is zero.

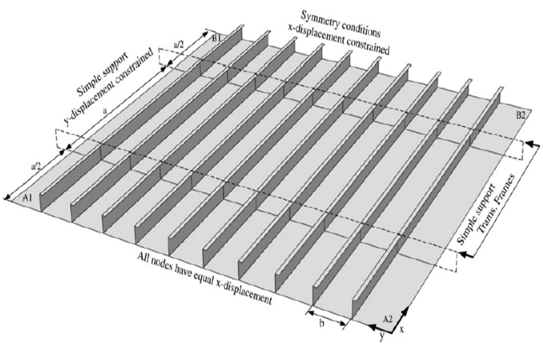


Fig 1.4: Stiffened panel model for non-linear FE analyses

1.5. Interaction Diagram

Interaction diagram is a graph illustrating the capacity of a structural member to resist a range of combinations of moment and axial force. By changing the location of the neutral axis, giving different size of compressive and tension zones, each case will lead to a different capacity calculated from the strain distribution. First the section is in pure compressions, then it will be over-reinforced until it reaches the point where it is balanced designed. After the point of balanced design the section will reach pure bending, then be under-reinforced and finally be in pure tension.

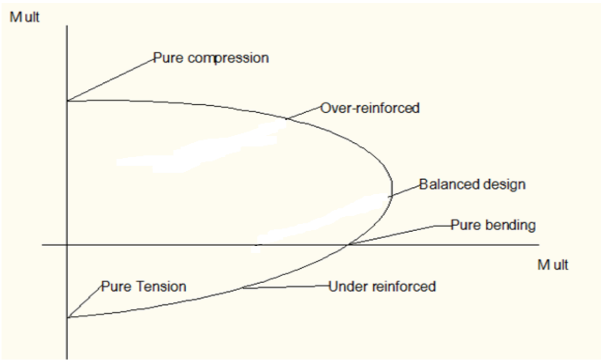


Fig 1.5: Interaction diagram

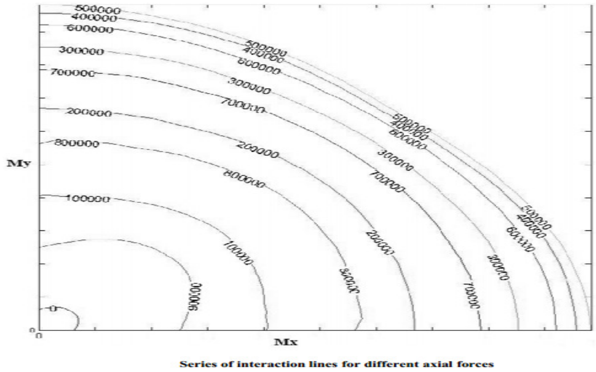


Fig 1.5.1: The shape of the interaction line varies with the section geometry and the level of the axial load

2. REVIEW OF LITERATURE

An analytical solution for buckling of simply supported rectangular plates subjected to sinusoidal in-plane compressive stress distribution at each end is presented as a superposed Fourier solution. The resulting in-plane stress solution consists of two normal stresses (x, y directions) and a shear stress which are nonlinearly distributed throughout the plane of the plate. The in-plane stress distribution in the present solution shows a decrease (diffusion) in axial stress (rx) as the distance from the loaded edges is increased. About its modeling information, Finite element(FE) models for all the plates involved in this study are meshed using Shell181,which incorporates quadratic deformation shapes in both in-plane directions and provide six degrees of freedom(DOF's) at each node. At high plate aspect ratios, this stress diffusion is more rapid and it remains essentially uniform at a reduced value for most part of the plate. The ultimate strength of a structure is defined as the point beyond which an additional increment of applied loading cannot be supported. A structure could collapse under axial loads, lateral pressure, shear loads or a combination of these actions. Ultimate strength under axial compression is the focus of this paper. Based on these stress can develop interaction curve.

3. ANALYSIS USING ANSYS SOFTWARE

Dr. John Swanson founded ANSYS. Inc in 1970 with a vision to commercialize the concept of computer simulated engineering, establishing himself as one of the pioneers of Finite Element Analysis (FEA). Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. A general purpose finite element software ANSYS is used for modeling, analysis and post processing of unstiffened plate with rectangular opening under axial compression. Modeling of unstiffened plate involves generation of a square of size 500 mm x 500 mm. To create the opening, area is generated using key points and connecting it by means of area command available in preprocessor. Using the 'Subtract areas' option available in the 'Booleans' operation under the 'modeling' part, the area is deleted. Thus the geometry of an unstiffened plate with opening at the centre of the plate is developed. The lines are meshed set using the 'size controls' available with the 'mesh tool' in 'meshing' part. Four noded finite linear strain elements (SHELL181) available in the ANSYS element library is used for discretisation of unstiffened plate. The element has six degrees of freedom per each node; three translations (UX, UY and UZ) and three rotations (RX, RY and RZ). This element is well suitable for analyzing the linear, large rotation, and/large strain linear applications. The finite element model of the square plate with circular and square opening is done. Simply supported boundary conditions along all the edges of the plate are used in the analysis. All the nodes along the four edges of the plate are constrained for deflection and rotation along the thickness direction (UZ, RZ = 0). Apart from it, the reactive edge is constrained against axial deformation (UY = 0). All the nodes along the unloaded edges are coupled for in plane displacement (UX) such that the displacements along the length of the plate are uniform. Both geometric and material linearity's are considered in the analysis. Large displacement static analysis with stress stiffening option is activated in geometric linear analysis. Bilinear isotropic rate independent hardening with Von Mises yield criteria is used in material linear analysis. Convergence study is performed to obtain an optimal element size to be used for the study.

4. SOFTWARE ANALYSIS

4.1 Stress Behavior of Plate

4.1.1 Changing the Plate Thickness

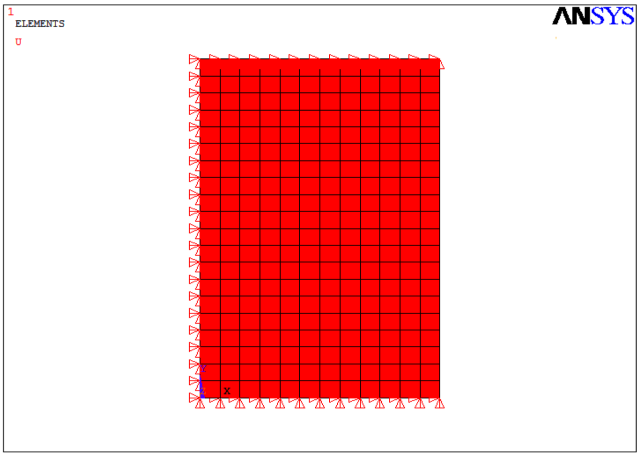
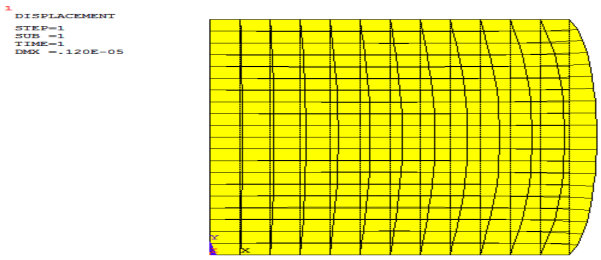
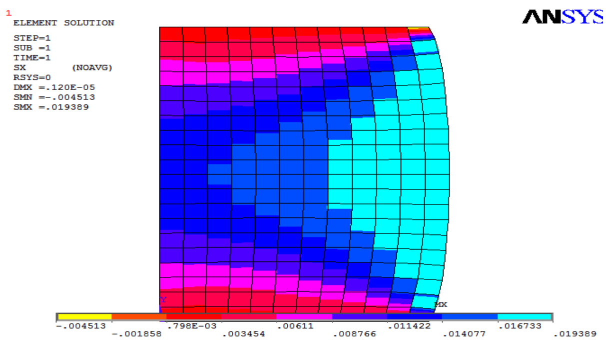


Fig 4.1.1: Model of Plate with Three Edges Fixed and One Edge Free

Deformed shape



Stress in X-direction



Stress in Y-direction

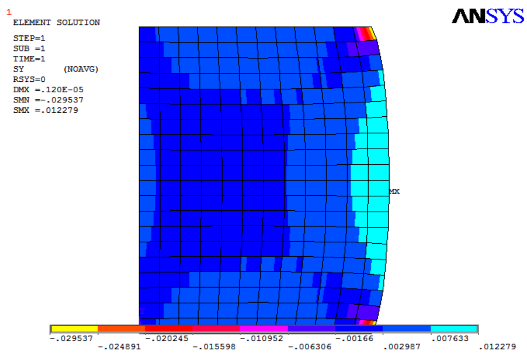


Fig 4.1.2: Deformed Shape, Stress in X And Stress in Y

From the above analysis, when thickness of plate increases (when the plate is subjected to only tensile loading,) stress acting on the plate decreases.
Above work is plotted as a graph with variation of thickness Vs Stresses

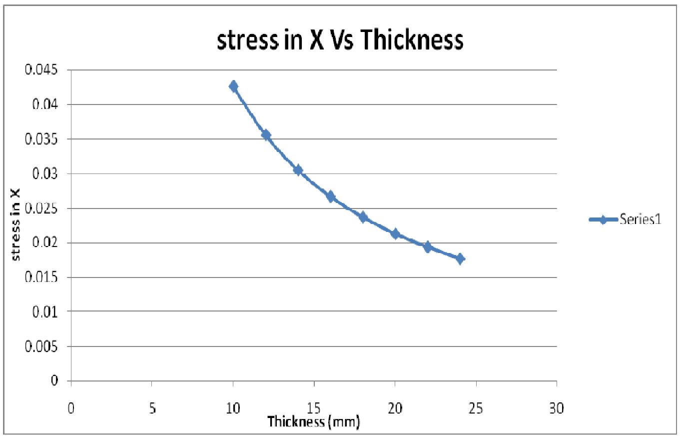


Fig 4.1.3: Graph of Stress in X Vs Thickness

From the above analysis, as thickness of plate increases (when the plate is subjected to tensile loading), then stress acting on the plate decreases.

4.1.2 Changing the Load

Behaviour of plate when load acting on it increases, When the thickness of plate is kept constant and the in plane compression and tension applied on the plate and also the loading is increasing.

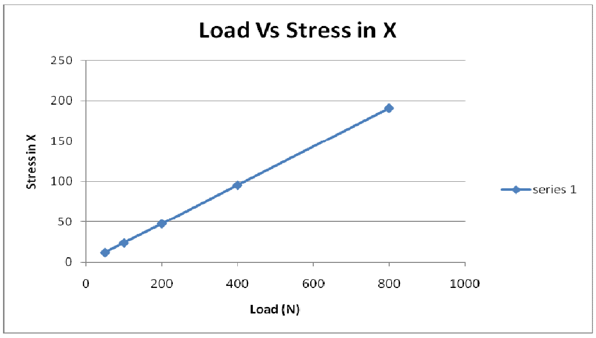


Fig 4.1.2: Variation of Load Vs Stress

4.2. Detailed Analysis of Meshing

Mesh refinement 1,3 and 5 is mainly taken for the analysis, where as 1 represents minimum refinement, 3 represents medium and 5 represents maximum mesh refinements. Meshing shows the accuracy of the output. Here the study verifies the accuracy of deflection in various mesh refinement.

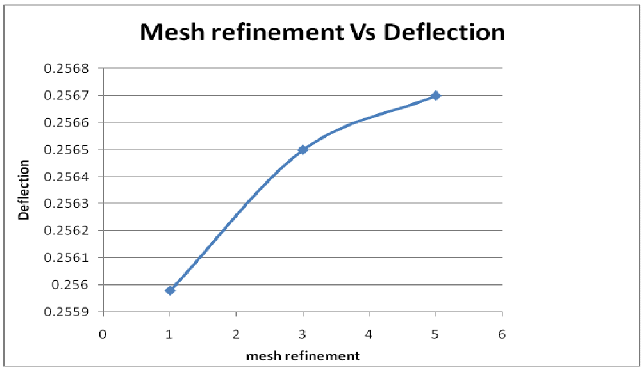


Fig 4.2: Mesh refinement Vs Deflection curve

5. STRESSES AND DEFLECTION OF PLATE UNDER VARYING BOUNDARY CONDITION

Table 5.1: boundary conditions and stresses

sl.	Boundary conditions	Load N	Stress in X	Stress in Y
1	Rectangular Plates with Three Edges Built In and the Fourth Edge Free	50	68.78	10.35
2	Two Opposite Edges Simply Supported, the Third Edge Free, and the Fourth Edge Built In	50	-4.568	-7.74
3	Three Edges Simply supported and the One Edge Built In	50	-4.38	-7.723
4	Two Opposite Edges Simply Supported and the Other Two Edges Clamped.	50	-4.324	-7.182
5	One Edge or Two Adjacent Edges Simply Supported and the Other Edges Built In.	50	-1.834	-1.864

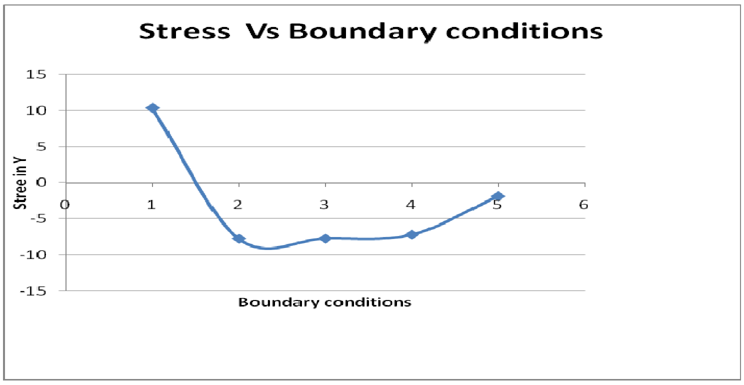


Fig 5.1: Stress-Boundary condition diagram

The above graph shows the variations of stress corresponding to different boundary conditions. Here reference load is taken as 50N. From this graph, we can easily identify how the plate is behaving under various boundary conditions. When Rectangular Plates with Three Edges Built In and the Fourth Edge Free (Let the boundary of the plate be clamped at $y = 0$ and $x = \pm a/2$ and free along $y = b$, and uniformly distributed load of intensity q) shows maximum stress both in X and Y direction.

Table 5.2: Boundary conditions and deflections

sl.	Boundary conditions	Load N	Deflections
1	One Edge or Two Adjacent Edges Simply Supported and the Other Edges Built In.	50	0.0364
2	Three Edges Simply supported and the One Edge Built In	50	0.1858
3	Two Opposite Edges Simply Supported and the Other Two Edges Clamped.	50	0.18688
4	Rectangular Plates with Three Edges Built In and the Fourth Edge Free	50	0.2567
5	Two Opposite Edges Simply Supported, the Third Edge Free, and the Fourth Built	50	0.277

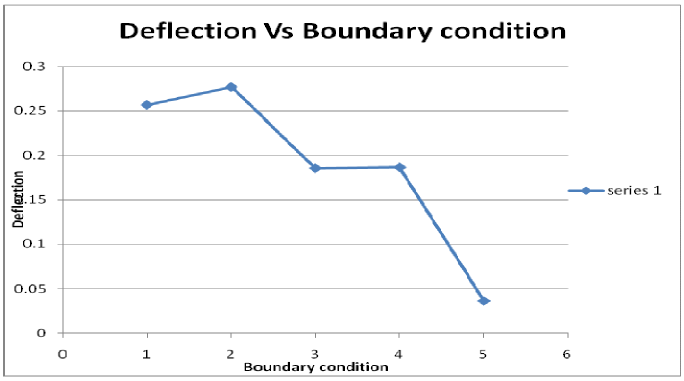


Fig 5.2 Deflection –Boundary conditions diagram

This graph shows the relation between boundary condition and deflection. Here also maximum deflection occurred at boundary condition 1.

6. MANUAL ANALYSIS

6.1. Rectangular Plates with Three Edges Built In and the Fourth Edge Free.

Plates with such boundary conditions are of particular interest as an integral part of rectangular tanks or retaining walls. Consequently, the uniformly distributed and the hydrostatic load must be considered first of all in that case.
Here plate of size 1600x2400x22mm is considered. Hence, b/a = 1.5.so for manual calculation Wmax = .01462*q*a^4/D.

Table 6.1: Comparison table

Comparison of manual result and software result				
b/a	Load (N) q	W(max)	Deflection (manual)	Deflection (software)
1.5	50	.01462*q*a^4/D	0.2177	0.2567
1.5	100	.01462*q*a^4/D	0.4355	0.6357
1.5	200	.01462*q*a^4/D	0.871	1.272
1.5	400	.01462*q*a^4/D	1.742	2.545
1.5	800	.01462*q*a^4/D	3.484	5.086

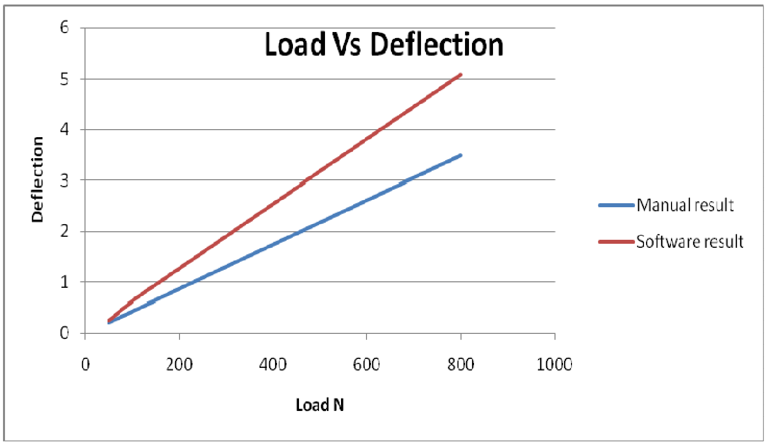


Fig 6.1 Load-Deflection diagram

6.2. Deflections for a Uniformly Loaded Plate with Two Opposite Edges Simply Supported, the Third Edge Free, and the Fourth Built.

Here also plate of size 1600x2400x22mm is considered. where b/a = 1.5.so for manual calculation Wmax = $0.0141qb^4/4$.

Table 6.2: Comparison table

Comparison of manual result and software result				
b/a	Load (N) q	W(max)	Deflection (manual)	Deflection (software)
1.5	50	.0141*q*a^4/D	0.21	0.2697
1.5	100	.0141*q*a^4/D	0.42	0.539
1.5	200	.0141*q*a^4/D	0.84	1.079
1.5	400	.0141*q*a^4/D	1.68	2.158
1.5	800	.0141*q*a^4/D	3.36	4.316

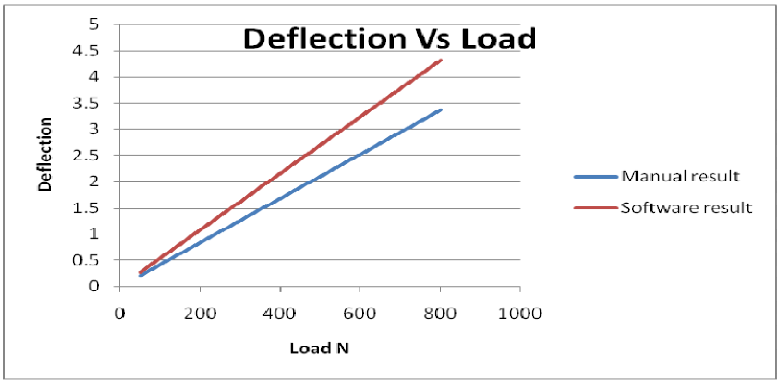


Fig 6.2: Load-Deflection diagram

6.3. Rectangular Plates with Three Edges Simply supported and the One Edge Built In

Let us consider a rectangular plate built in along the edge y = b/2 and simply supported along the other edges. The deflection of the plate under any lateral load can be obtained by combining the solution for the plate with all sides simply supported.

b/a = 1.5, hence $0.0064qa^4/D$ this equation is used for the manual calculation.

Table 6.3: Comparison Table

Comparison of manual result and software result				
b/a	Load (N) q	W(max)	Deflection (manual)	Deflection (software)
1.5	50	.0141*q*a^4/D	0.0953	0.1858
1.5	100	.0141*q*a^4/D	0.191	0.3718
1.5	200	.0141*q*a^4/D	0.381	0.74366
1.5	400	.0141*q*a^4/D	0.763	1.487
1.5	800	.0141*q*a^4/D	1.525	2.974

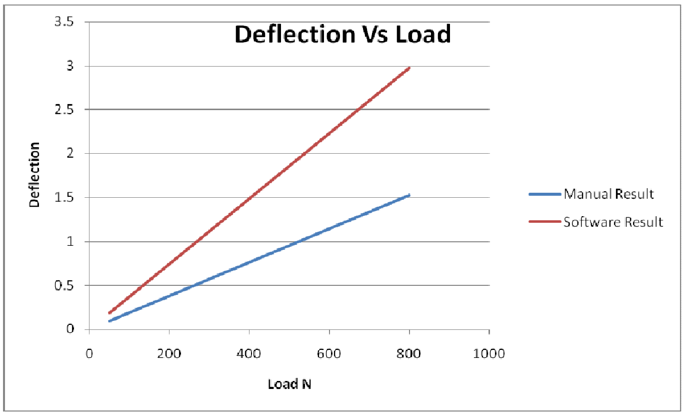


Fig 6.3: Load- deflection diagram

6.4. Rectangular Plates with Two Opposite Edges Simply Supported and the Other Two Edges Clamped

Assume that the edges x =0 and x = a of the rectangular plate, is simply supported and that the other two edges are clamped. The deflection of the plate under any lateral load can be obtained by first solving the problem on the assumption that all edges are simply supported and then applying bending moments along the edges y = ±b/2 of such a magnitude as to eliminate the rotations produced along these edges by the action of the lateral load.

Table 6.4: Comparison Table

Comparison of manual result and software result				
b/a	Load (N) q	W(max)	Deflection (Manual result)	Deflection (Software Result)
1.5	50	.00531*q*a^4/D	0.0791	0.18688
1.5	100	.00531*q*a^4/D	0.158	0.3738
1.5	200	.00531*q*a^4/D	0.361	0.74752
1.5	400	.00531*q*a^4/D	0.634	1.495
1.5	800	.00531*q*a^4/D	1.265	2.99

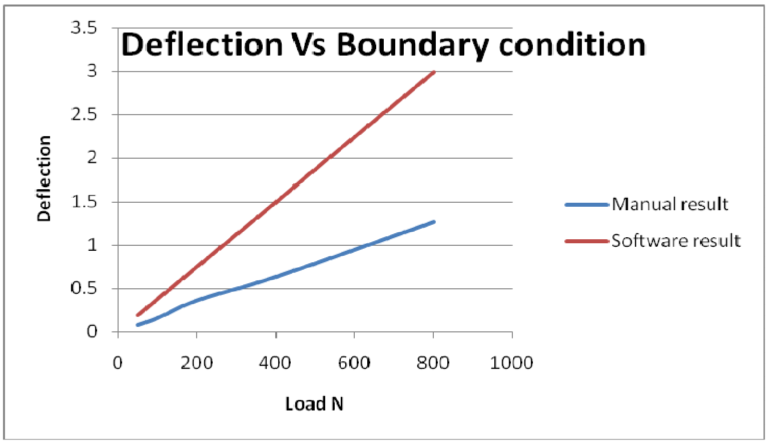


Fig 6.4: Load- Deflection diagram

6.5 Rectangular Plates with One Edge or Two Adjacent Edges Simply Supported and the Other Edges Built In.

Let us begin with the case of a plate simply supported at the edge y =0 and clamped along the other edges.

Table 6.5: Comparison table

Comparison of manual result and software result				
b/a	Load (N) q	W(max)	Deflection (Manual result)	Deflection (Software Result)
1.5	50	.00226*q*a^4/D	0.0336	0.0364
1.5	100	.00226*q*a^4/D	0.0673	0.0728
1.5	200	.00226*q*a^4/D	0.1346	0.1458
1.5	400	.00226*q*a^4/D	0.269	0.2914
1.5	800	.00226*q*a^4/D	0.538	0.5828

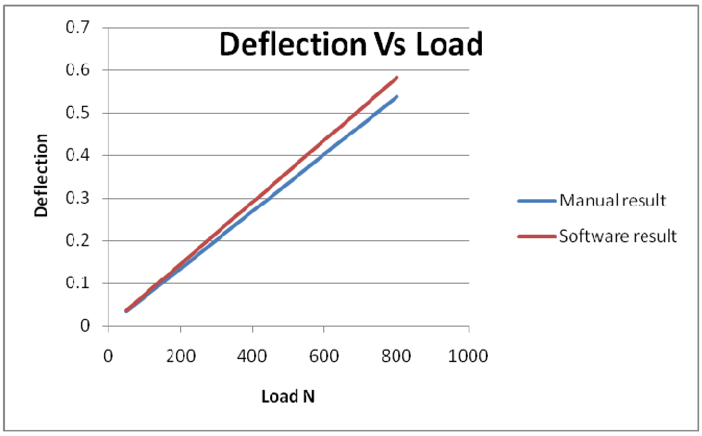


Fig 6.5: Load- deflection diagram

6.6 Corrections In Manual And Software Results:

From the above findings, we can observe that there is some correction between manual and software result. This is shown below,

Table 6.6: Correction table

Correction Table			
Reference load fixed as 50N			
Sl no.	Boundary condition	Deflection manual result	Deflection software result
1	One Edge or Two Adjacent Edges Simply Supported and the Other Edges Built In.	0.0336	0.0364
2	Two Opposite Edges Simply Supported, the Third Edge Free, and the Fourth Built	0.21	0.2697
3	Rectangular Plates with Three Edges Built In and the Fourth Edge Free	0.2177	0.2567
4	Three Edges Simply supported and the One Edge Built In	0.0953	0.1858
5	Two Opposite Edges Simply Supported and the Other Two Edges Clamped.	0.0791	0.1278

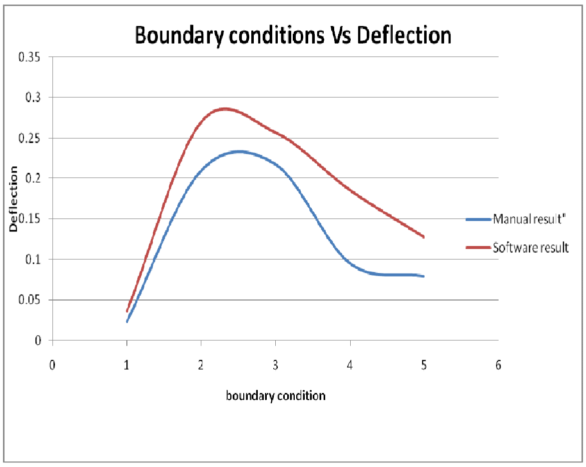


Fig 6.6: Boundary conditions – Deflection diagram

From the above graph, it is clear that, there is some variations in the manual and software result.

The graph showing the % of correction is,

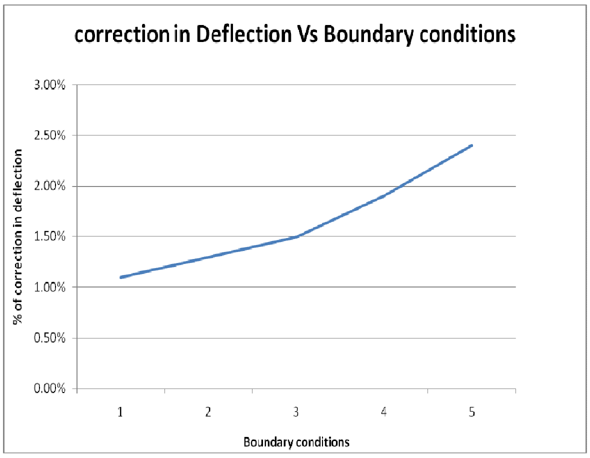


Fig 6.7: Correction diagram

7. RELATION BETWEEN LOAD AND BOUNDARY CONDITION AT YIELD STRESS 250 MPA

Table 7.1: Load at yield stress 250MPa

Sl.	Boundary conditions	Load N	Yield stress MPa
1	Two Opposite Edges Simply Supported and the Other Two Edges Clamped.	159.892	250
2	Three Edges Simply supported and the One Edge Built In	159.871	250
3	One Edge or Two Adjacent Edges Simply Supported and the Other Edges Built In.	129.971	250
4	Two opposite edges simply supported , the Third Edge Free, and the Fourth Built	120.89	250
5	Edges Built In and the Fourth Edge Free	100.8594	250

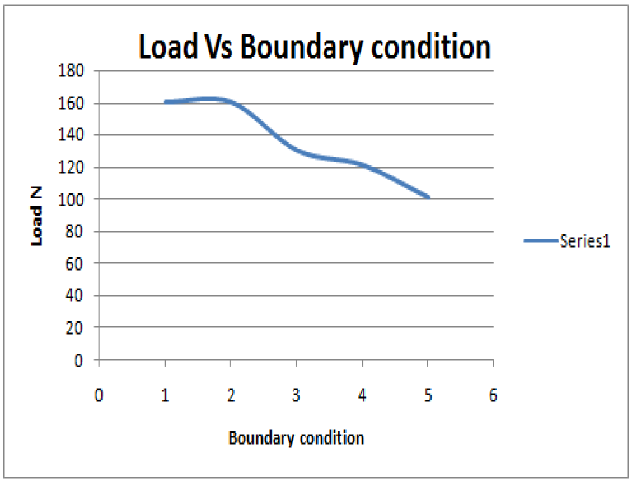


Fig 7.1: Load- boundary condition diagram

8. STUDY OF DEVELOPMENT OF INTERACTION CURVE

In this case plate is subjected to in plane and out of plane loading. This shows, when the plate subjected to out of plane loading, how the variation of stresses affecting on the plate.

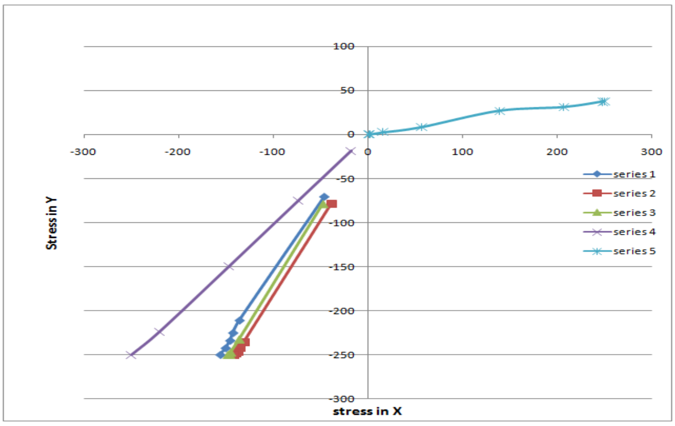


Fig 8.1: Graph showing stress in X and Y

Series 1 - Two Opposite Edges Simply Supported and the Other Two Edges Clamped

Series 2 - Three Edges Simply supported and the One Edge Built In

Series 3 - One Edge or Two Adjacent Edges Simply Supported and the Other Edges Built In

Series 4 - Two Opposite Edges Simply Supported, the Third Edge Free, and the Fourth Edge Built In

Series 5 - Rectangular Plates with Three Edges Built In and the Fourth Edge Free

8.2 Stress graph due to Combined loads

Rectangular Plates with Two Opposite Edges Simply Supported and the Other Two Edges Clamped.

In this case plate is subjected to in plane and out of plane loading. This shows, when these two loads act, how the stresses affecting on the plate.

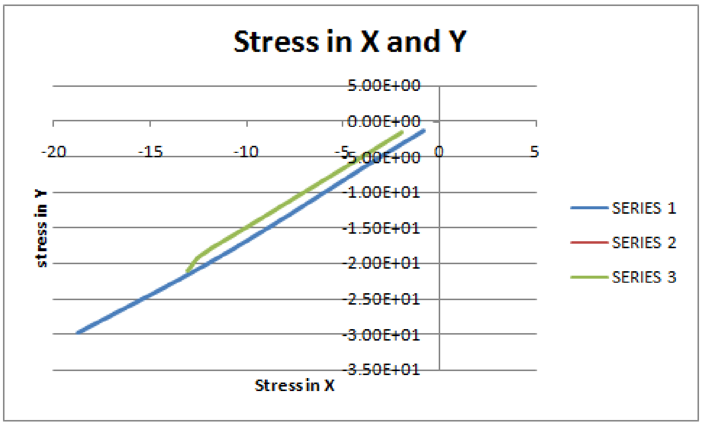


Fig 8.2: Stress graph

Series 1 – In plane loading

Series 2 – out of plane loading

Series 3 – combined loading

8.3 Development of Interaction Curve

Plate with Four Edges Simply Supported

Table 8.3: Combined loading

Load	Stress in x	Stress in y	Yield stress
10	-9.992	-5.99	8.885
40	-39.969	-11.993	35.541
100	-79.89	-59.99	72.89
150	-112.89	-87.32	107.333
180	-135.65	-100.56	159.213
210	-155.99	-110.02	178.99
250	-180.99	-115.34	213.45
270	-217.56	-115.89	250
320	-234.55	-110.93	275.88
360	-250	-100.89	298.33
400	-275.89	-87.98	310.998
450	-321.223	-76.98	349.89
500	-365.632	-61.564	368.98

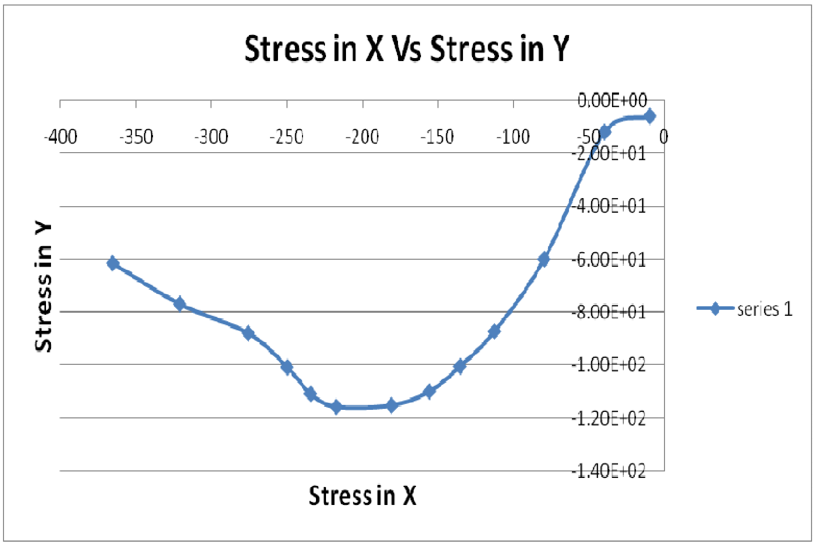


Fig 8.3: Interaction curve

9. CONCLUSION

Through this project, structural behaviour of thin plate was studied and also find out the stress behaviour of plate under variation of thickness and loading conditions. In addition that, received an idea about the yield stress of plate under varying loading conditions. When the Interaction curve was developed, stress in X and Y direction was increased, except in the case of four edges simply supported plate. Stress in Y started to decrease, when the yield stress reached 250 MPa. This was only happening in the case of four edge simply supported plate. This implies that the structure is safe within the limit of 250MPa and will start to fail after this limit.

Future scope of the project

- To study the structural behavior of plate under varying thickness and loading conditions using software.
- To study, how varying boundary conditions affected on the plate.
- To develop interaction curve of thin plate under varying boundary condition.

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